Scientific Thinking and Inquiry

P.1. Broad Concept: Scientific progress is made by asking relevant questions and conducting careful investigations. As a basis for understanding this concept, and to address the content in this grade, students should develop their own questions and perform investigations.

Students:

1. Know the elements of scientific methodology (identification of a problem, hypothesis formulation and prediction, performance of experimental tests, analysis of data, falsification, developing conclusions, reporting results) and be able to use a sequence of those elements to solve a problem or test a hypothesis. Also, understand the limitations of any single scientific method (sequence of elements) in solving problems.
2. Know that scientists cannot always control all conditions when obtaining evidence, and when they are unable to do so for ethical or practical reasons, they try to observe as wide a range of natural occurrences as possible so as to be able to discern patterns.
3. Recognize the cumulative nature of scientific evidence.
4. Recognize the use and limitations of models and theories as scientific representations of reality.
5. Distinguish between a conjecture (guess), hypothesis, and theory as these terms are used in science.
6. Plan and conduct scientific investigations to explore new phenomena, to check on previous results, to verify or falsify the prediction of a theory, and to use a crucial experiment to discriminate between competing theories.
7. Use hypotheses to choose what data to pay attention to and what additional data to seek and to guide the interpretation of the data.
8. Identify and communicate the sources of error inherent in an experiment.
9. Identify discrepant results and identify possible sources of error or uncontrolled conditions.
10. Select and use appropriate tools and technology to perform tests, collect data, analyze relationships, and display data. (The focus is on manual graphing, interpreting graphs, and mastery of metric measurements and units, with supplementary use of computers and electronic data gathering when appropriate.)
11. Formulate and revise explanations using logic and evidence.
12. Analyze situations and solve problems that require combining concepts from more than one topic area of science and applying those concepts.
13. Apply mathematical relationships involving linear and quadratic equations, simple trigonometric relationships, exponential growth and decay laws, and logarithmic relationships to scientific situations.
14. Recognize and deal with the implications of statistical variability in experiments, and explain the need for controls in experiments.

Examples *Students participate in science fair projects based on their research, such as the effects of friction on motion, or why fluids and gases flow the way that they do (P.1.1).*

Students research how Einstein coordinated his theory of relativity with experimental results from two different astronomical stations in 1919 (P.1.2).

SCIENTIFIC THINKING AND INQUIRY (CONTINUED)

Students make a timeline of evidence for the duality of light as both wave and particle, starting with Newton's observations of prisms and moving into modern uses of light in technology, such as satellites (P.1.3).

Students investigate the origins and uses of Maxwell's equations and Newton's laws (P.1.4).

Students explore Faraday's exhibitions and try to replicate experiments he used to "wow" the crowds. For instance, they build an instrument to measure the charge. They build Faraday's cage and stop the charge with a conductor, then describe attributes of objects, systems and the relationships with the language of mathematics (P.1.6).

Students speculate about what approach they would use to solve a problem such as the value of little g in the gravitational equation $F = Gmm/r^2 = mg$. *Students figure out what equation to use to solve the problem and to interpret the data (P.1.7).*

Students use tools such as ramps, timers, steel balls, projectile launchers, metersticks, and ping-pong balls to develop the concepts behind one- and two-dimensional motion (P.1.10).

Students prove that g is 9.8 meters per second squared on planet Earth and provide evidence. They determine the value for g on another planet (P.1.11).

Students use levers and pulleys to illustrate the movement of human joints. Students could also use fluids to demonstrate blood flow from large to small arteries (P.1.12).

Students investigate the magnetic field of the Earth or the value of the constant g in Earth's orbit. They compare these results with the magnetic fields of other planets and offer hypotheses about how Earth technology might need to be adapted to work in other fields and other forces of gravity (P.1.13 and P1.14).

MOTION AND FORCES

P.2. Broad Concept: Newton's laws of motion and gravitation describe and predict the motion of a vast variety of objects. As a basis for understanding this concept,

Students:

1. Explain that when the net force on an object is zero, no acceleration occurs; thus, a moving object continues to move at a constant speed in the same direction, or, if at rest, it remains at rest (Newton's first law).
2. Explain that only when a net force is applied to an object will its motion change; that is, it will accelerate (according to Newton's second law, $F = ma$).
3. Predict and explain how when one object exerts a force on a second object, the second object always exerts a force of equal magnitude but of opposite direction and force back on the first: $F_{1\ on\ 2} = -F_{2\ on\ 1}$ (Newton's third law).
4. Explain that Newton's laws of motion are not universally applicable, but they provide very good approximations, unless an object is moving close to the speed of light, has a very large mass, or is small enough that quantum effects are important.

MOTION AND FORCES (CONTINUED)	
5.	Explain that every object in the universe exerts an attractive force on every other object. Know the magnitude of the force is proportional to the product of the masses of the two objects and inversely proportional to the distance between them: $F = G\,m_1m_2/r^2$.
6.	Investigate and explain how the Newtonian model — the three laws of motion plus the law of gravitation — makes it possible to account for such diverse phenomena as tides, the orbits of the planets and moons, the motion of falling objects, and Earth's equatorial bulge.
7.	Explain how a force acting on an object perpendicular to the direction of its motion causes it to change direction but not speed.
8.	Demonstrate that a motion at constant speed in a circle requires a force that is always directed toward the center of the circle.
9.	Solve kinematics problems involving constant speed and average speed.
10.	Apply the law $F = ma$ to solve one-dimensional motion problems involving constant forces (Newton's second law).
11.	Use and mathematically manipulate appropriate scalar and vector quantities $(F, v, a, \Delta r, m, g)$ to solve kinematics and dynamics problems in one and two dimensions.
12.	Solve problems in circular motion, using the formula for centripetal acceleration in the following form: $a = v^2/r$.
13.	Create and interpret graphs of speed versus time and the position and speed of an object undergoing constant acceleration.
Examples	*Students send a toy car with a stuffed animal inside down a ramp and into a barrier, such as a brick. After they watch the toy fly, they measure and interpret the results (P.2.1).* *Students draw free body diagrams to represent the forces acting upon common objects, such as a textbook on a countertop, a person walking or lifting an object, etc. (P.2.2).* *Students propose modifications to improve skateboards or bicycles to make them safer, faster, or less expensive (P.2.2).* *Students run cars into solid obstacles, then measure and evaluate the consequences of the crashes (P.2.3).* *Students explain how Kepler's laws describe gravity before there was a term for gravity. They explain how Newton made the connections and gave the phenomena a name (P.2.6).* *Students look around the classroom for examples of torque, such as the movement of doors with hinges, balancing stacks of textbooks on the edges of countertops, or examining the movement of their own hand, arm, and elbow. They make some measurements and calculate the torque (P.2.7).* *Students swing keys on a lanyard to demonstrate the force and acceleration. They create free body diagrams and take measurements and calculations (P.2.8).* *Students build Hero's Engines to investigate conservation of angular momentum, circular motion, and properties of fluids (P.2.8).* *Students make a presentation detailing how an understanding of acceleration and velocity can make one a better driver (P.2.9).*

MOTION AND FORCES (CONTINUED)

Students explore the topic of projectile motion through the trajectory of the rocket in the movie Vanilla Sky. They measure range and flight time and use this data to calculate maximum height and the launch angle (P.2.11).

Students decide the conditions for putting a satellite into orbit around the planet (information is available at www.fearofphysics.com/Satellite/satellite.html) (P.2.12).

CONSERVATION OF ENERGY AND MOMENTUM

P.3. Broad Concept: The laws of conservation of energy and momentum provide independent approaches to predicting and describing the motion of objects. As a basis for understanding this concept,

Students:

1. Recognize that when a net force, F, acts through a distance, Δx, on an object of mass, m, which is initially at rest, work, $W = F\Delta x$, is done on the object; the object acquires a velocity, v, and a kinetic energy, $K = \frac{1}{2}mv^2 = W = F\Delta x$.
2. Describe how an unbalanced force, F, acting on an object over time, Δt, results in a change, $\Delta p = F \Delta t$, in the object's momentum.
3. Describe how kinetic energy can be transformed into potential energy and vice versa (e.g., a bouncing ball).
4. Explain that momentum is a separately conserved quantity that is defined in one dimension as $p = mv$. Know that the momentum of a system can be changed only by application of an external impulse, $J = F\Delta t$. Know that the total momentum of a closed system cannot change, regardless of the interchange of momentum within it.
5. Define power as the rate at which work is done: $P = W/\Delta t$.
6. Identify the joule, J, as the SI unit for work and energy; the unit for power is the watt, W; and the unit for impulse and momentum is the $kg \cdot m/s$.
7. Describe the conditions under which each conservation law applies.
8. Calculate kinetic energy using the formula $K = \frac{1}{2}mv^2$.
9. Calculate changes in gravitational potential energy, U, due to elevation changes, Δh, near the Earth, using the relation $\Delta U = mg\Delta h$.
10. Solve problems involving conservation of energy in simple systems such as that of falling objects.
11. Apply the law of conservation of mechanical energy to simple systems.
12. Calculate the momentum of an object as the product $p = mv$.
13. Solve problems involving perfectly inelastic collisions in one dimension using the principle of conservation of momentum.
14. Calculate the changes in motion of two bodies in one-dimensional elastic collisions in which both energy and momentum are conserved.

CONSERVATION OF ENERGY AND MOMENTUM (CONTINUED)	
Examples	*Students design protective containers, using only paper or plastic, for uncooked eggs and test the containers by dropping them from a one-story building (P.3.1).* *Students toss softballs barehanded back and forth, increasing the distance between them without losing control so they can connect the ideas of impulse and momentum (P.3.2).* *Students measure bouncing balls using the mass of the balls, the initial height, and the final height of the bounce. They use this data to compare kinetic and potential energy (P.3.3).* *Students use a set of colliding balls to observe the conservation of momentum or by dropping a small ball (e.g., tennis ball) and a large ball (e.g., basketball). The smaller ball is placed on top of the larger, and both are dropped at the same time (P.3.4).* *To increase a bowling average, students investigate whether they should throw the ball faster or get a heavier ball (P.3.4).* *Students explain the difference between recycling and reusing in terms of power usage and energy conservation. They interview an engineer who works with a DC utility company or recycling center (P.3.5).* *Students measure and calculate the power, work, and energy they generate by walking upstairs. They measure the distances and times involved and then combine that information with their known mass (P.3.6).* *Students build roller coasters (with toy parts) and obtain velocity of the roller coaster at any time by measuring its changing height (P.3.8).* *Students interview engineers or technicians from an airport, construction company, or architecture firm about the practical uses of calculations of kinetic energy or potential energy in their work (P.3.9).* *Students build a system of balanced and unbalanced weights, levers, and objects that can fall and pass energy on to another part of the system. They predict the kinds of motion expected by making the energy calculations ahead of time (P.3.11).* *Students conduct a series of toy car crashes, then take measurements and make calculations.* *Students play pool to investigate elastic collisions firsthand (P.3.12).* *Students roll balls of clay down a ramp and observe the results of collisions when objects stick together (P.3.13).*

MECHANICS OF FLUIDS

P.4. Broad Concept: All objects experience a buoyant force when immersed in a fluid. As a basis for understanding this concept,

Students:

1. Explain that the buoyant force on an object in a fluid is an upward force equal to the weight of the fluid it has displaced.
2. Recognize that a change in the pressure at any point in a fluid is accompanied by an equal change at all other points (Pascal's principle).
3. Identify that the pressure in an incompressible fluid (e.g., water) is a function of density, ρ; depth, y; and gravitational acceleration, g.
4. Solve problems involving floating and sinking bodies using Archimedes' principle.
5. Understand that Bernoulli's principle, $p + \frac{1}{2}\rho v^2$ = constant, is a consequence of conservation of mechanical energy applied to a moving, incompressible fluid, and apply it accurately.
6. Solve problems involving a confined, isothermal gas using Boyle's law.

Examples

Students float a flat object in water and measure the displacement of water. They add weights to the float and measure the displacement again. Students calculate the density of the float. They repeat the experiment using another liquid for comparison (P.4.1).

Students predict the changes that will occur when they squeeze a tube of toothpaste at different positions along the tube (P.4.2).

Students use sealed syringes (without needles) to experience the incompressibility of air (P.4.3).

Students determine the kind of metal in an unknown object by immersing the object in different liquids and measuring the displacement. They determine the densities of the metals and use that data to determine the unknown (P.4.5).

Students demonstrate the gas laws through "no-hands" can crushing. They boil water in the can, and then quickly invert the can in cold water (P.4.6).

HEAT AND THERMODYNAMICS

P.5. Broad Concept: Energy cannot be created or destroyed; however, in many processes energy is transformed into the microscopic form called *heat energy*, that is, the energy of the disordered motion of atoms. As a basis for understanding this concept,

Students:

1. Recognize that heat flow and work are two forms of energy transfer between a system and its surroundings.
2. Describe and measure that the change ΔU in the internal energy of a system is equal to the sum of the heat flow, Q, into the system and the work, W, done on the system: $\Delta U = Q + W$ (first law of thermodynamics).
3. Describe and measure the work, W, done by a heat engine as the difference between the heat flow, Q_{in}, into the engine at high temperature and the heat flow, Q_{out}, out at a lower temperature: $W = Q_{in} - Q_{out}$.

HEAT AND THERMODYNAMICS (CONTINUED)

4. Explain that thermal energy (commonly called *heat*) consists of random motion and the vibrations and rotations of atoms, molecules, or ions.

5. Describe how in everyday practice, temperature is measured with a *thermometer,* a device containing a part that has a *thermometric parameter* (a quantity that changes with temperature).

6. Investigate and describe how the absolute temperature of an object is proportional to the average kinetic energy of the thermal motion of its microscopic parts.

7. Recognize that the absolute temperature is measured in kelvins (K); 0 K is the temperature at which the average kinetic energy of the microscopic parts of the system is an irreducible minimum.

8. Explain that on the everyday Celsius scale, 0°C = 273.15 K, which is very close to the freezing point of pure water at atmospheric pressure, 100°C = 373.15 K is very close to the temperature at which pure water boils at a pressure of 1 atmosphere.

9. Describe that when two objects at different temperatures are in contact, heat energy always flows from the object at a higher temperature to the object at a lower temperature by the process of conduction until the two are at the same (intermediate) temperature.

10. Explain the process of convection: Because the density of fluids varies with temperature, the warmer parts of a fluid tend to move into and mix with the cooler parts, resulting in a transfer of heat energy from place to place.

11. Explain that all objects emit electromagnetic radiation at a rate that rises very rapidly with their temperature. As a result, know that a warmer body that is in the line of sight with a cooler one will transfer net energy to it, cooling down while the cooler object warms up.

12. Demonstrate that in all internal energy transfers, the overall effect is that the energy is spread out uniformly.

13. Recognize that entropy is a quantity that measures the order or disorder of a system and that it is larger for a more disordered system.

14. Explain the law, "the entropy of a closed system will always either increase or remain the same," based on the statistics of the behavior of immense numbers of atoms or molecules that governs all closed systems (second law of thermodynamics).

15. Use a p-V diagram to graph simple thermodynamic processes for an ideal gas (for which $pV = nRT$); for example, an isothermal process is described by a hyperbola, an isobaric process by a horizontal straight line, and an isochoric process by a vertical straight line.

16. Use the second-law-based Carnot efficiency formula, $\eta = (T_{in} - T_{out})/T_{in}$, to calculate the maximum possible efficiency for a heat engine.

17. Given heat input and work output data, calculate the efficiency of a real heat engine or human being (e.g., a well-trained athlete working out for eight hours may consume 7,000 kcal of food (20 MJ) a day and do work at the rate of ¼HP (187 W) over an eight-hour period during that day. What is his or her thermodynamic efficiency?).

18. Describe a refrigerator as a heat engine operated "in reverse."

HEAT AND THERMODYNAMICS (CONTINUED)	
Examples	*Students trace the transformation of energy from the electric current that enters a CD player to the sound that can be heard as music (P.5.1).* *Students investigate why starting an automobile left outside in subzero temperatures is more difficult than starting an automobile left in an unheated garage (P.5.2).* *Students diffuse food coloring in hot and cold water and describe what happens (P.5.4).* *Students create insulated houses out of Styrofoam poster board. They expose the houses to sunlight, and then compare what is happening inside the houses that have higher temperatures (P.5.6).* *Students expose beakers of water at different temperatures to room temperature, then measure how long it takes for each beaker to reach equilibrium with room temperature (P.5.9).* *Students place a drop of food coloring into water in three different beakers: cold, room temperature, and hot. They record and discuss the results (P.5.10).* *Students handle cold objects and then hold hands or rub their hands together to experience the transformation of energy from one form to another (P.5.11).* *Students build a tower from dominoes or cards and examine the tendency of those systems toward greater disorder. They discuss the energy that would have to be used to prevent that disorder (e.g., using glue, sealing the tower in a vacuum, etc.) (P.5.13).* *Students use the Internet to research simple ways to test the ideal gas laws, then develop and carry out a series of experiments such as the effects of temperature on the volume of a balloon or the response of PEEPS (marshmallow Easter candy) in a vacuum chamber (P.5.15).* *Students read excerpts from* The Practice Effect, *by David Brin. In the universe created in Brin's book, the laws of thermodynamics work in reverse. Students look for contradictions to the laws and use evidence from the text to support their conclusions (P.5.16).* *Students investigate energy-efficient technologies introduced recently into automobiles, washer-dryers, refrigerators, lightbulbs, etc. (P.5.17 and P.5.18).*

WAVES

P.6. Broad Concept: Waves carry energy from place to place without the transfer of matter. As a basis for understanding this concept,

Students:

1. Explain that waves carry energy from one place to another.
2. Observe and describe that a mechanical wave is a disturbance in a medium. For example, a sound wave in air is a slight variation in the pressure of the air surrounding a vibrating object, such as a bell.

WAVES (CONTINUED)

3. Explain that waves conform to the superposition principle: Any number of waves can pass through the same point at the same time, and the amplitude, *A*, of the resulting wave at that point at any time is the sum of the amplitudes of the superposed waves. Use the principle of superposition to describe the interference effects arising from propagation of several waves through the same medium.

4. Demonstrate how standing waves on a stretched string are the result of the superposition of the wave moving away from the source and the wave reflected back from the other end of the string.

5. Explain that longitudinal waves can propagate in any medium, but transverse waves can propagate only in solids.

6. Describe that sound in a fluid medium is a longitudinal wave whose speed depends on the properties of the medium in which it propagates.

7. Differentiate electromagnetic waves from mechanical waves (i.e., electromagnetic waves are not disturbances in a medium. Rather, such waves are a combination of a varying electric field and a varying magnetic field, each of which, in varying, gives rise to the other. Electromagnetic waves can therefore propagate in empty space).

8. Know that radio waves, light, and X-rays are different wavelength bands in the spectrum of electromagnetic waves whose speed, *c*, in a vacuum is approximately 3×10^8 m/s (186,000 miles/second).

9. Explain how Scottish physicist James Clerk Maxwell used Ampère's law and Faraday's law to predict the existence of electromagnetic waves and predict that light was just such a wave. Know these predictions were confirmed by Heinrich Hertz, whose confirmations thus made possible the fields of radio, TV, and many other technologies.

10. Predict and explain how light travels through a transparent medium at a speed, *v*, less than *c*. The index of refraction of the medium is defined to be $n = c/v$.

11. Explain that when a light ray passes from air into a transparent substance, such as glass, having index of refraction *n*, it is refracted through an angle given by Snell's law, $n \sin \theta_i = n \sin \theta_r$, where θ_i is the angle of incidence of the ray and θ_r is the angle of refraction.

12. Describe waves in terms of their fundamental characteristics of speed, *v*; wavelength, λ; frequency, *f*; or period, *T*, and amplitude, *A*, and the relationships among them. For example, $f\lambda = v$, $f = 1/T$. Solve problems involving wavelength, frequency, and wave speed.

13. Identify transverse and longitudinal waves in mechanical media such as springs, ropes, and the Earth (seismic waves).

14. Identify the phenomena of interference (beats), diffraction, refraction, the Doppler effect, and polarization, and that these are characteristic wave properties.

15. Use Snell's law to calculate refraction angles and analyze the properties of simple optical systems.

16. Identify electromagnetic radiation as a wave phenomenon after observing interference, diffraction, and polarization of such radiation.

WAVES (CONTINUED)	
Examples	*Students research the Louisiana levee system before and after Hurricane Katrina to see the power of waves and rising water (P.6.1).* *Students conduct an investigation to determine if the size, shape, distance from, or position of a listener to a stereo speaker affects sound quality (P.6.2).* *Students use barriers (small pieces of wood) and different motions with other small pieces of wood in colored water to create and observe the superposition of wave motion and develop interference and diffraction patterns (P.6.3).* *Students explore the idea of sound waves by putting their ears to a desktop and listening to the sound as it travels through the solid material of the desk (P.6.6).* *Students compare the clarity of sound generated by "cup and string" and "cup and wire" telephones (P.6.6).* *Students research and report on how the concept of waves support the technology that they use every day, from cell phones and wireless Internet to instant and text messaging. They predict how the waves used in current technology could be used in future machines (P.6.9). With a prism and a sunbeam, students work to create and analyze the resulting rainbow (P.6.10).* *After reading articles on how the ideas about waves were developed, students reduce the article to an abstract that gives the essence of the reading, including the history, the science, and the social context of the ideas. Students design a refraction apparatus in which the light is refracted more than four times as it passes from one end to the other (P.6.11).* *Students use a guitar, or build their own stringed instrument, to determine the relationship of wave variables (P.6.12).* *Students investigate wave properties in useful technological advances, such as noise reduction (interference), jewel cutting (diffraction), Mach speed (Doppler effect), and sunglasses (polarization) (P.6.14).*

ELECTROMAGNETISM

P.7. Broad Concept: The phenomena that fall into the categories known as electrostatics and electromagnetism are due respectively to the behavior of stationary and moving charged particles. As a basis for understanding this concept,

Students:

1. Determine how an electric charge, q, exists in two kinds: positive (+) and negative (–). Know that like charges repel each other, and unlike charges attract each other with an *electrostatic force* whose magnitude is given by Coulomb's law, $F = kq_1q_2/r_{12}^2$, where k is a constant. Know that the unit of electric charge is the coulomb (C).
2. Explain that around any point charge, Q, there is an electric field, $E = k\,Q/r^2$. Know that another charge, q, located in this field will experience a force of magnitude $F = qE$ and that the unit of electric field is the newton per coulomb (N/C).

ELECTROMAGNETISM (CONTINUED)
3. Calculate electric potential (voltage): When a charge, q, is pulled through a field, E, over a distance, d, work, $W = qd$, is done. The work done per unit charge, W/q, is the electric potential, V. Thus, $V = Ed$. The unit of electric potential is the volt, V; 1 V = 1 N·m/C.
4. Know that most materials fall into one of two categories: electrical conductors, through which an electric charge can flow easily under the influence of an electric field, and electrical insulators (or dielectrics), through which a charge cannot flow easily.
5. Explain that a source of electromotive force (EMF) is any device (such as a battery) that furnishes a steady potential between two terminals. Know that if a conducting loop is supplied between the two terminals, an electric current, I, will flow. Know, too, that current is measured in the number of coulombs per second that flow past a given point in the conductor: $I = q/t$ and that the unit of electric current is the ampere (A); 1 A = 1 C/s.
6. Give evidence that almost all metals are good electrical conductors; nevertheless, they do offer some resistance (*friction*) to the flow of current. Know that the greater the potential difference between the ends of the conductor, the greater the current; the greater the resistance, the less the current. Know, too, that for most metals and many other conductors, the current is determined by Ohm's law, $V = IR$. A conductor that conforms to this rule is called an *ohmic conductor.*
7. Explain that any resistive element in a DC circuit transforms electrical energy into thermal energy at a rate (power) given by Joule's law, $P = IV$, which in an ohmic element has the special form $P = I^2R = V^2/R$.
8. Recognize that plasmas, the fourth state of matter, contain ions and free electrons in such numbers that they are electrically neutral overall, but the many free charges they contain make them good conductors of electricity. Recognize that the glowing gas in a neon light is plasma.
9. Explain the properties of transistors and their role in electric circuits.
10. Explain that magnetic materials and electric currents (moving electric charges) are sources of magnetic fields, and they experience forces due to magnetic fields of other sources.
11. Demonstrate how changing magnetic fields produce electric fields (Faraday's law), thereby inducing currents in nearby conductors.
12. Explain how electric and magnetic fields are vector fields that contain energy.
13. Investigate and explain how various wavelengths in the electromagnetic spectrum have many useful applications such as radio, TV, microwave radars and ovens, cellular telephones, infrared detectors, optical cables, and X-ray machines.
14. Explain the magnitude of the force on a moving particle with charge, q, in a magnetic field, B, is $qvB \sin \theta$, where v is the speed of the particle, B is the magnitude of the magnetic field, and θ is the angle between the directions of v and B.
15. Describe the advantages to alternating current over direct current for power distribution networks.
16. Calculate the power dissipated in any resistive circuit element by using Joule's law in the appropriate form.
17. Predict the current in simple direct current electric circuits constructed from batteries, wires, and resistors.
18. Solve problems involving Ohm's law in series and parallel circuits.

ELECTROMAGNETISM (CONTINUED)	
	19. Determine the direction of a magnetic field produced by a current flowing in a straight wire and in a coil (use the right-hand rule).
	20. Explain the operation of electric generators, motors, and transformers in terms of Ampère's law and Faraday's law.
Examples	*Students observe the action of a magnet on metal filings. They create drawings — geometric or artistic patterns — of electric field interactions by putting down positive and negative charges and then drawing the field lines around each charge with respect to the surrounding charges (P.7.1).* *Students build working electroscopes using insulated copper wire, small glass jars, aluminum foil, and plastic and foam boards for generating static electricity. Students detect the charge and show the force produced (P.7.2).* *Students determine which battery is the most cost efficient from a collection of different size batteries (C, D, A, AA, AAA, and 9V) (P.7.3).* *Students investigate why some household appliances have really thick electrical cords (P.7.4).* *Students build circuits in series and parallel with lightbulbs and switches. They measure current and voltage and use this activity to explore Ohm's law and the flow of current (P.7.5, P.7.17, and P.7.18).* *Students investigate some current limitations associated with transistors and the kinds of solutions some engineers are inventing (information is available at www.intel.com/education/sections/section6/index.htm) (P.7.9).* *Students investigate maglev devices by researching and building these devices, and measuring the force due to the magnetic field (P.7.14).* *Students investigate the competition between Edison's and Westinghouse's inventions (P.7.15).* *Students create a simple circuit using pencil lead as a resistor. They measure the current and voltage and investigate the relationships between length and cross-sectional area of the resistor, resistivity, and power (P.7.17).* *Students build and decorate electric houses where the lighting is provided by simple series and parallel circuits (P.7.18).* *Students investigate magnetic fields, electromagnets, and induced current by making a motor work (P.7.20).*

NUCLEAR PROCESSES

P.8. Broad Concept: Nuclear processes are those in which an atomic nucleus changes; they include radioactive decay of naturally occurring and man-made isotopes and nuclear fission and fusion processes. As a basis for understanding this concept,

Students:

1. Explain how the research of Marie Curie, later in collaboration with her husband, Pierre, spurred the study of radioactivity, and led to the realization that one kind of atom may change into another kind, and so atoms must be made up of smaller parts. Rutherford, Geiger, and Marsden found these parts to be small, dense nuclei surrounded by much larger clouds of electrons.
2. Recognize that the nucleus, although it contains nearly all of the mass of the atom, occupies less of the atom than the proportion of the solar system occupied by the sun.
3. Explain how the mass of a neutron or a proton is about 2,000 times greater than the mass of an electron.
4. Describe Niels Bohr's model of the atom, its electron arrangement, and the correlation with the hydrogen spectrum.
5. Explain Albert Einstein's photoelectric effect.
6. Describe Louis de Broglie's insight into the wave-particle duality.
7. Describe the Heisenberg uncertainty principle and how it arises naturally from the fact that matter has wavelike properties.
8. Explain the principle of special relativity and some of its implications, including the mass-energy equivalence equation, $E = mc^2$.
9. Demonstrate how the mass of a stable nucleus is always less than the sum of the masses of the protons and neutrons comprising it. Know this is especially true of the elements in the region of the periodic table around iron (26 protons, 30 neutrons) and generally less so of elements with greater or lesser atomic numbers than this.
10. Explain that if lighter atoms are fused to form atoms closer to iron, or heavier atoms are split to form atoms closer to iron, there is a mass loss. Explain that according to the principle of conservation of mass-energy, this mass loss must be accompanied by a release of energy according to Einstein's mass-energy equation. Know that, because c^2 is such a large number ($\approx 9 \times 10^{20}$ m^2/s^2), a small mass loss leads to a large energy release.

Examples

Students predict the age of a fossil based on the rate of radioactive decay of several radioactive isotopes (P.8.1).

Students research the current international debates over nuclear power, as well as modern methods for treating nuclear waste (P.8.1).

Students examine the work of a particle accelerator and identify why certain particles are used for different kinds of experiments because of their masses (information is available at www.fnal.gov) (P.8.3).

Students investigate spectral lines that are used to determine the kinds of elements that are present in stars (P.8.4).

Students create a chain reaction out of dominoes, representing nuclear decay, half-life, or the chain reaction required for nuclear fission of reactors and bombs (P.8.8).

NUCLEAR PROCESSES (CONTINUED)	
	Students research the historical, social, and technological aspects of the Manhattan Project to take part in a debate or a role-play session (P.8.8). *Students calculate the mass defect of iron versus hydrogen. They compare the difference in amount of energy produced by both mass defects and determine why the sun burns hydrogen but not iron (P.8.9).* *Students investigate the process of nuclear fusion in the sun. They detail how the elements are fused from hydrogen into helium, helium into carbon, etc., and how this process offers the energy that comes to the Earth (P.8.10).*